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Some Reactions of Pelagic Fish to Light as Recorded by Echo-Sounding

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on the Staff of the Ministry of Agriculture and Fisheries

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By I. D. RICHARDSON, B.Sc.
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Some Reactions of Pelagic Fish to Light

INTRODUCTION

VERY LITTLE HAS BEEN PUBLISHED on the behaviour of shoals of pelagic fish and the way in which external factors determine this behaviour. Nevertheless, fishermen have very definite ideas on the best time of day, the best state of the tide and the best winds for making good catches of pelagic fish such as herrings, sprats and pilchards, and from this knowledge something of the behaviour of pelagic fish can be understood.

The fisherman knows that the best catches are made towards dusk or about dawn. He knows that dull days are better than clear bright ones. He knows that "sheer" water is not so good as cloudy water. Similarly, he knows that nets which are shot along the direction of the current rarely produce such a large catch as they would do had they been placed across the current.

Fishermen's observations normally depend on the size of the catch and this, in turn, depends on the amount of fish in the area and on the way in which the nets are fishing, but not on direct observation on the shoals. To obtain a truer picture of the behaviour of pelagic fish shoals in the open sea, direct observations must be made, or one must use an instrument, such as the echo-sounder, which is not affected by wind, light or current. Ronald Balls (1) has used the echo-sounder to explain some of the observations he has made on the size of the catch under various conditions. Krefft and Schüler (2) have also used the echo-sounder in this way.

The material for the present paper consists of a number of echo-sounder tracings showing the way in which fish shoals react to light. Other tracings, showing the reaction of shoals to wind and current, will be considered separately. As the echo-sounder has been used extensively throughout this paper, two earlier papers in which it is fully described should be consulted, viz., Hodgson and Richardson (3) and Hodgson (4). In those papers warning is given that the vertical extent of the shoal, as represented on the tracing, does not correspond to the actual extent of the shoal. More recent work has shown that the vertical extent is represented much more accurately than was previously thought.

I. REACTION OF FISH SHOALS TO DAYLIGHT

1. Sprats

The most complete picture of the diurnal movement of a pelagic fish was obtained when carrying out some work on the sprat shoals of the Thames estuary. The ship was kept over a shoal of sprats from mid-afternoon until mid-morning the next day, during which time the echo-sounder was running continuously. The time was noted on the tracing at regular intervals and other observations such as the time of sunrise and sunset were noted upon it. For convenience the tracings were cut into sections, each one of which was marked with the time at which the record was obtained. The sections were then joined together in their proper sequence and photographed (Fig. 1).

Because the shoal moved somewhat during the course of the night, the depth of water varied but the important point to note is that it rose until after dark, when it was well up towards the surface of the sea, and then as the light increased at dawn, it descended towards the sea bed. At 1550 hours, one hour and ten minutes before sunset, the shoal started its upward migration with the upper limit at 25 feet from the surface. At 1630 hours it reached 19 feet, by 1655 hours 18 feet. In the next 20 minutes, as the last light of the sun left the sky, it rose further until the noise of the fish breaking the surface of the water could be heard. Throughout the night the shoal remained well up towards the surface.

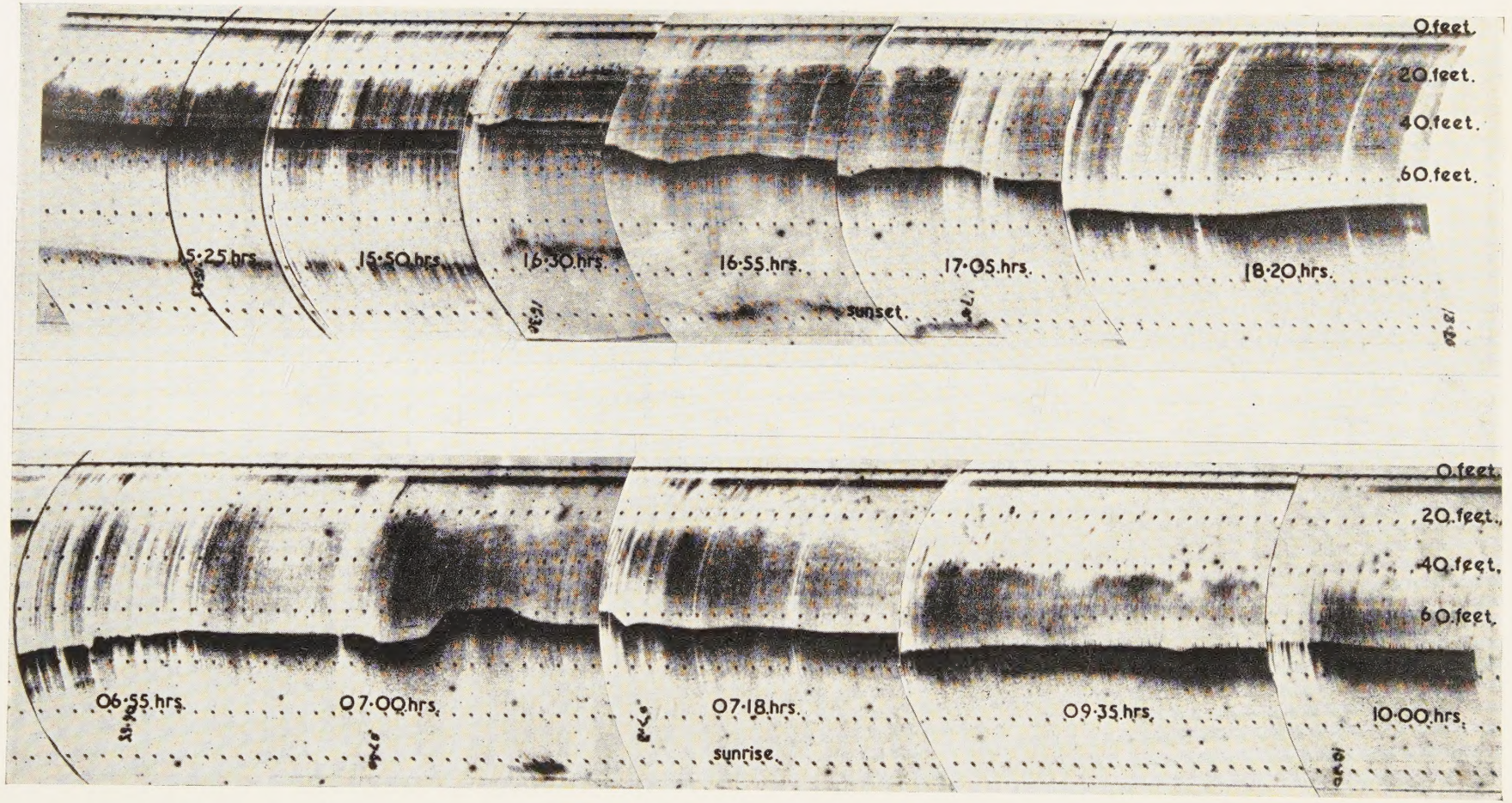


FIG. 1. Tracings taken at times indicated have been joined in sequence to show the way in which the shoal moves up towards the surface near sunset, remains up at the surface and then moves down to greater depths as the light increases at dawn.

During the night the shoal moved some distance, so that next morning it was in a part of the Thames which was deeper. In these tracings 70 feet of water is shown below the ship. The shoal remained with its upper limit at 50 feet from the surface and did not extend to the sea bed. During the previous afternoon, when the shoal was in a shallower place, the fish were packed in a dense mass close to the bottom.

This vertical migration, of which Fig. 1 is an actual picture, is not an isolated phenomenon, for, on dull days the sprats in the Thames are nearer the surface than they appear to be on bright sunlit days.

2. **Herrings**

(*a*) *In the North Shields Area*

It has been impossible to obtain a series of echo-sounder tracings of herrings from the North Shields area as complete as that for the sprat; nevertheless, the observations show that there is a diurnal migration. The herrings in this area do not usually swim in such tightly packed shoals as do the herrings of the Yorkshire or East Anglian coasts. The difference may partly be due to the fact that in the one case—off Shields between April and June—the fish are shoaling for feeding, whereas, in the other two regions mentioned the shoals are made up of fish gathering together prior to spawning.

Nevertheless, the shoals off the Northumberland coast are large enough to be located with the echo-sounder, as Cushing (5) and Skipper Ronald Balls in his book "Fish on the Spotline" (6) have shown. Skipper Balls has proved that using the echo-sounder wisely in these waters results in an overall increase in the size of the catch for the season. During the hours of darkness the shoals are found to be nearer the surface of the sea and at a lower level during the day.

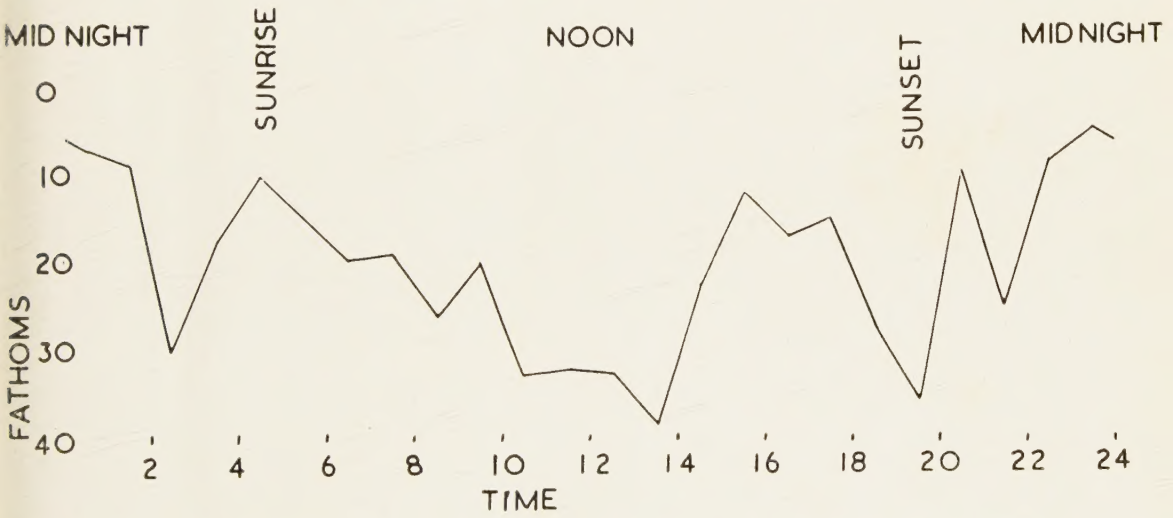


FIG. 2. The average depth of shoals located off North Shields during each hour of the day are plotted to show that there is a tendency for the shoals to be higher at night than during the day.

In 1949 the Ministry's Research Vessel *Sir Lancelot* worked in the area of the North Shields fishery for some weeks and during this time the echo-sounder was run continuously. Shoals of herrings were recorded both by day and by night in approximately equal numbers, the ratios being 100 shoals per hour's darkness to 108 per hour's daylight, but it will be seen from Fig. 2 that there was a difference between the average depth of the top of the shoals during the hours of darkness and daylight. Only tracings of fish found in water deeper than 40 fathoms have been used, in order to eliminate any effect of greater turbidity in shallower water.

The average depth of the shoal in daylight is 23·9 fathoms and in darkness 15·7 fathoms. In calculating these average depths, which were tested, and shown to be significantly different, only those shoals which were located in full daylight or darkness have been used and any which were located in intermediate lights at dusk and dawn have been neglected.

(*b*) *In the Yorkshire Coast Area*

Similar examples of the diurnal movement of herrings have been found in the fishery that takes place during August and September off the Yorkshire coast. The fish on these grounds are found to remain well down at about twenty fathoms or more from the surface during the hours of daylight. Towards darkness the fish begin to rise until the top of the shoal is ten fathoms from the surface. In 1947 and 1948, the shoals never rose above the ten-fathom mark throughout the whole night, but could always be seen on the echo-sounder as dense shoals with the top at ten fathoms from the surface, where they would remain until the increasing illumination at dawn forced them to a lower level. Tracings taken during 1948 show clearly (Fig. 3) that after dark the tops of the shoals lie at 10 fathoms from the surface. This upper limit of the "swim", as the upward migration is called, is of great importance to the fishing industry for it affects the catches of the drifters very greatly. The drift net which is used in the fishery has about seven fathoms of lint suspended on two-fathom strops. The bottom of the net is therefore 9-10 fathoms below the surface. Obviously, if the fish never rise above this ten-fathom mark, the nets should be sunk lower in the water than is usually the case in this fishery. Efforts were made to find out why the fish remained at this level through the night but no conclusive evidence was obtained. It was thought that there might be a thermocline on the grounds, but in 1948, although observations were made in the neighbourhood of the shoals, no sudden temperature gradient was found.

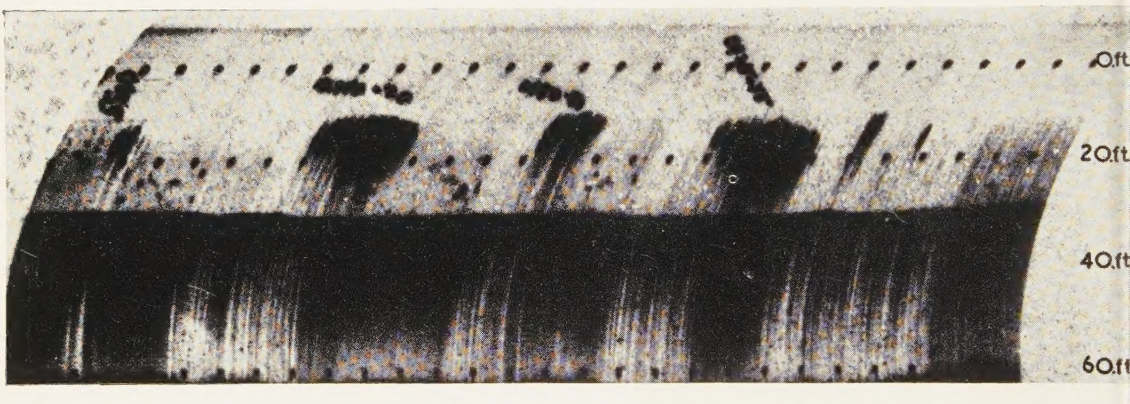


FIG. 3. The tracing is of shoals of herrings located off the Yorkshire coast at night. The top of the shoal is seen to be at 10 fathoms from the surface.

One series of temperature observations is given below. Other series also failed to indicate a clear thermocline during this season.

Depth in Metres	*Depth in Fathoms*	*Temperature in °C.*
2	1·1	14·0
6	3·3	14·1
10	5·5	13·9
14	7·6	13·4
18	9·8	13·1
22	12·0	12·9
26	14·2	12·0
30	16·4	12·0

In 1949 the shoals behaved similarly in this area except towards the end of the season when they would often appear to be at a higher level and in some cases up as high as four fathoms from the surface.

In 1951 a sharp temperature gradient was found on the fishing grounds off the Yorkshire coast. The readings are given below:

Depth in Metres	*Depth in Fathoms*	*Temperature in °C.*
5	2·7	14·05
10	5·5	14·00
15	8·2	13·95
20	10·9	12·30
25	13·7	9·95
30	16·4	9·80
35	19·1	9·75
50	27·3	9·70

Between 10·9 and 13·7 fathoms there was a 2·35° C. temperature change. If the fish reacted to temperature gradients by not traversing them in their upward migration at night, the fish should remain at about 13·7 fathoms and certainly never come up to as high as 10·9 fathoms.

A tracing on the echo-sounder was often detected at a depth of 10-11 fathoms but this tracing was not always obtained although the temperature gradient was present. The tracing could not, therefore, have been produced by the thermocline but might have been given by organisms which were sometimes present at the same level as the temperature change. When the mid-water trawl was towed through the layer, large quantities of jellyfish (*Cyanea*) and small whiting about 3 inches in length, were caught. These animals may have given rise to the echo.

Figure 4 is a photograph of a tracing showing the layer of what is believed to be jellyfish and whiting. Four herring shoals are also shown. These shoals can be seen to be above the jellyfish layer and they extend down through the layer. The top of the herring shoals lies at about 6 fathoms and the bottom at about 13 fathoms. The herring shoals were found well down towards the sea bed at 30 fathoms during the day and must have passed through the temperature gradient in their upward migration to the depths at which they were located at night. This is not an isolated record of the herring shoals rising above the temperature gradient. Any suggestion that the level at which the shoals were to be found at night was due to the presence of a thermocline, can therefore be abandoned.

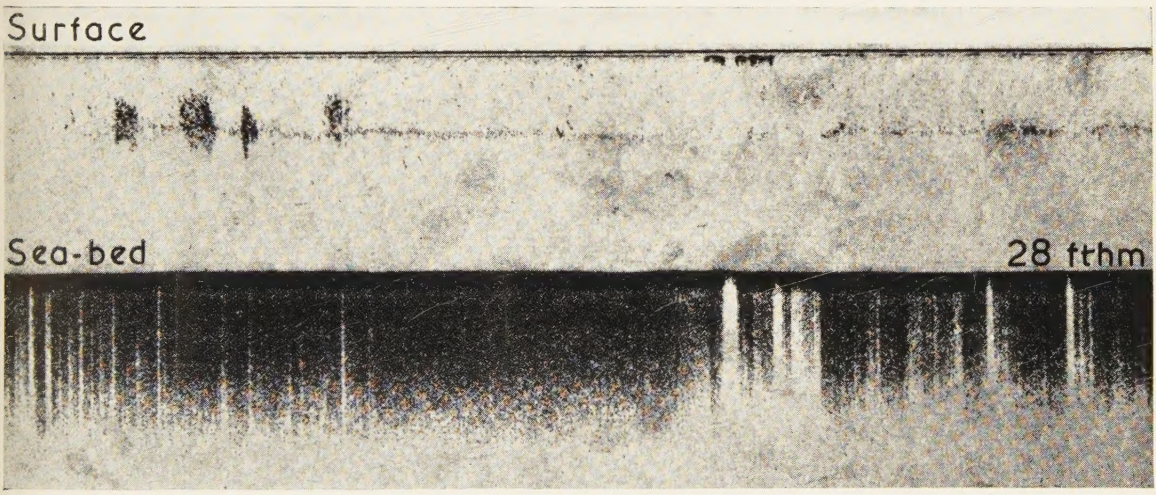


FIG. 4. A tracing obtained off the Yorkshire coast in 1951. Four shoals of herring can be seen to the left of the tracing. Also a tracing believed to be produced by jellyfish and small Whiting can be seen at a depth of approximately 11 fathoms. The layer of jellyfish, etc., was associated with the thermocline.

(c) *In the East Anglian Area*

In East Anglian waters the herrings are again usually concentrated, and are easily located on the sounder. Although the fish are always said to rise at sunset, (and it is this time which is supposed to yield the catches), it is often found that the fish strike the nets suddenly, so that within a few minutes they are heavy with fish; and as this sudden filling

of the nets can take place at any time of the night and occasionally in daylight, it was assumed that the East Anglian herrings behaved differently from those of the more northern grounds. The difference of behaviour in East Anglian waters, as interpreted by the fishermen, is that there is a sudden upward movement of the fish followed shortly by an equally sudden downward movement. This "swim" as it is called, is of very short duration and quite unlike that which is seen in other fisheries, where, once the fish have risen, they stay well up towards the surface until dawn.

The theory of the rapid East Anglian swim gained considerable support from Skipper Ronald Balls, who, using the Marconi 424 (Spotlight) echo-sounder, found that when he got indications of large shoals on the grounds and shot his nets immediately, he very rarely made a good catch. It was therefore assumed that if the fish could not be caught by the drift net, they had returned to the bottom extremely quickly and so missed the net. He also found that he obtained very few tracings of shoals in East Anglian waters. He said that this was due to the fish remaining close to the sea bed, where the echo-sounder could not locate them during most of the day, and then suddenly swimming up towards the surface before returning quickly to the bottom.

If this theory of rapid swim is accepted, it would appear that there is some radical difference between the behaviour of the herrings in the East Anglian area and that of the other areas which have been discussed. The tracings obtained from the East Anglian area have, therefore, been analysed to see whether any support could be obtained for the theory of

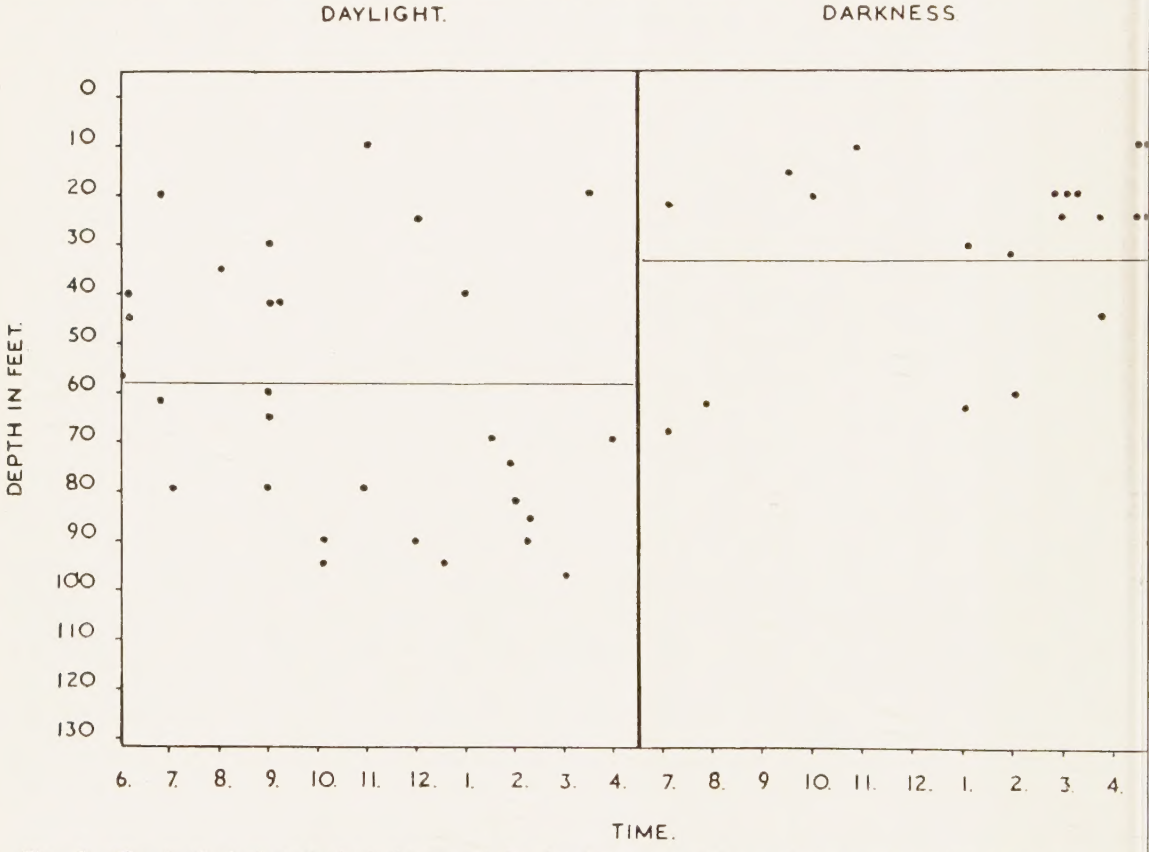


FIG. 5. The depths in feet at which the top of the shoal was recorded are plotted against time and the average depth for the level of the shoals during complete darkness and full daylight is indicated. Only shoals found in water of 130–135 feet are used.

rapid swim. Unfortunately, it was found difficult to keep a ship over a shoal of herrings during the East Anglian season to obtain a record of a shoal over a number of hours except on two occasions when there were few drifters in the vicinity and there was no fear of over-riding their nets. On one occasion, the *Sir Lancelot* remained over a shoal from 1000 hours until 1700 hours, when the shoal was lost until 0600 hours the next morning.

During the period for which tracings were obtained the shoal was seen to vary between 15 feet from the surface and 53 feet, a variation which might have been due to some extent to patches of turbid water affecting the penetration of light in the sea. It is apparent that the shoal was well off the bottom, (the bottom being at 100 feet), during the whole of the daylight period and that towards sunset there was a rise in the level of the shoal. The decreasing light penetration towards sunset can be seen in the Secchi disc readings taken at this time. The interesting thing to note is that there was no indication of a sudden swim by the fish, for the surface of the shoal throughout the whole period of 7 hours only varies in depth over a range of 40 feet. The absence of shoals during the thirteen-hour period from 1700 hours to 0600 hours the next morning, when the shoal was again located, may be due to the shoals moving with the tide and then returning on the next tide, but in the absence of further data no sound explanation can be essayed. It is possible that the fish scattered too much for the sounder to locate them. Alternatively the fish might have been on the bottom, but if this was so and the fish were still in shoals they would have been located by the sounder as they were in Fig. 1 which shows sprat shoals on the bottom.

In Fig. 5, all the tracings which were obtained in water of 130-135 feet in depth during the season of the East Anglian herring fishing are plotted against time of day and it will be seen that, although there is quite a considerable range in the level of the shoals, many were located during the hours of darkness, the difference in number being due to the difficulty of surveying the area at night when herring drifters were lying to their nets. Two time periods have been taken in constructing the graph. The first is from 0600 hours to 1630 hours and the second from 1900 hours to 0430 hours. By taking these ranges, the period of " between lights ", at sunset and dawn, has been cut out, and it has been possible to work out the mean value for the depth at which the shoals remain during the hours of daylight and darkness. The difference in the means is statistically significant, being 24·9 feet, even though no account of turbidity or varying light intensity is taken during daylight, the shoals being higher at night than in the hours of daylight. In no case did our instrument reveal a shoal on the sea bottom.

A further test was applied to the tracings obtained during the East Anglian season : this was to take the level of the tops of the shoals and plot them against the number of tracings obtained. Graphs were constructed for each depth of the sea, two of which are shown in Fig. 6. If the theory of a sudden East Anglian swim holds good, these graphs would show more shoals at greater depths ; or, to put it another way, fewer towards the surface, where

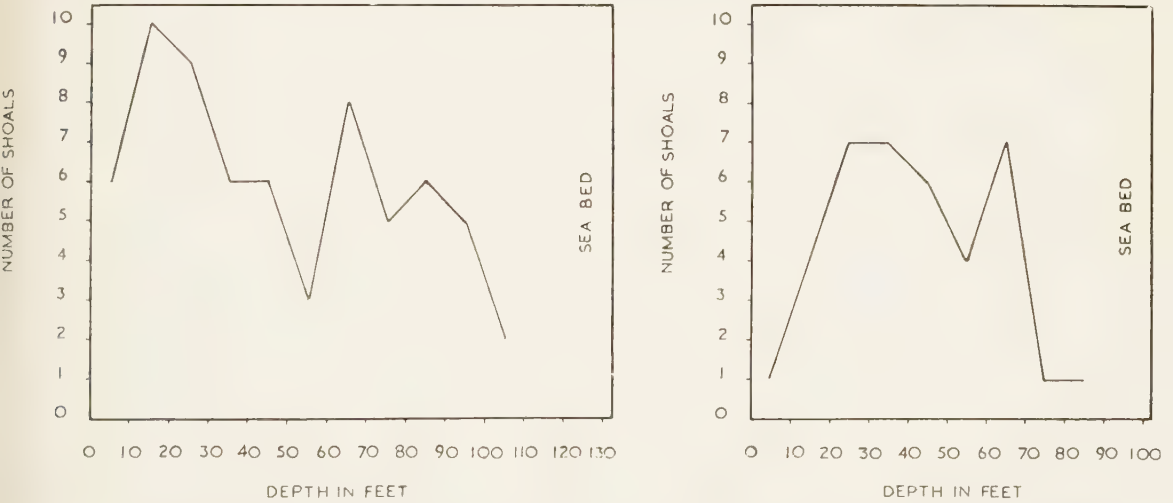
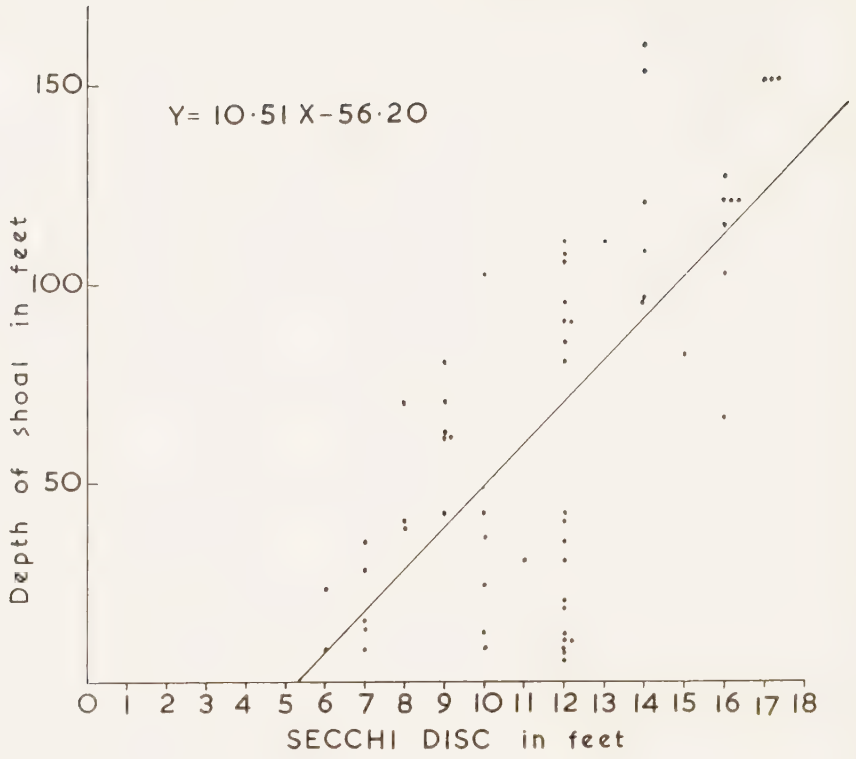


FIG. 6. The number of shoals occurring at each depth in water of 130–135 feet in one case, and 100–105 feet in the other are plotted to show that the number of shoals is at a minimum towards the sea bed.

the fish, according to the theory, do not linger. This is not found to be the case. In many of the graphs there appeared to be more traces towards the surface and in no case are traces found near the bottom or in the last twenty feet above the sea bed. The absence of traces close to the surface is probably caused by the inability of the echo-sounder to locate shoals above the depth of the transmitters, which are situated in the ship's hull.



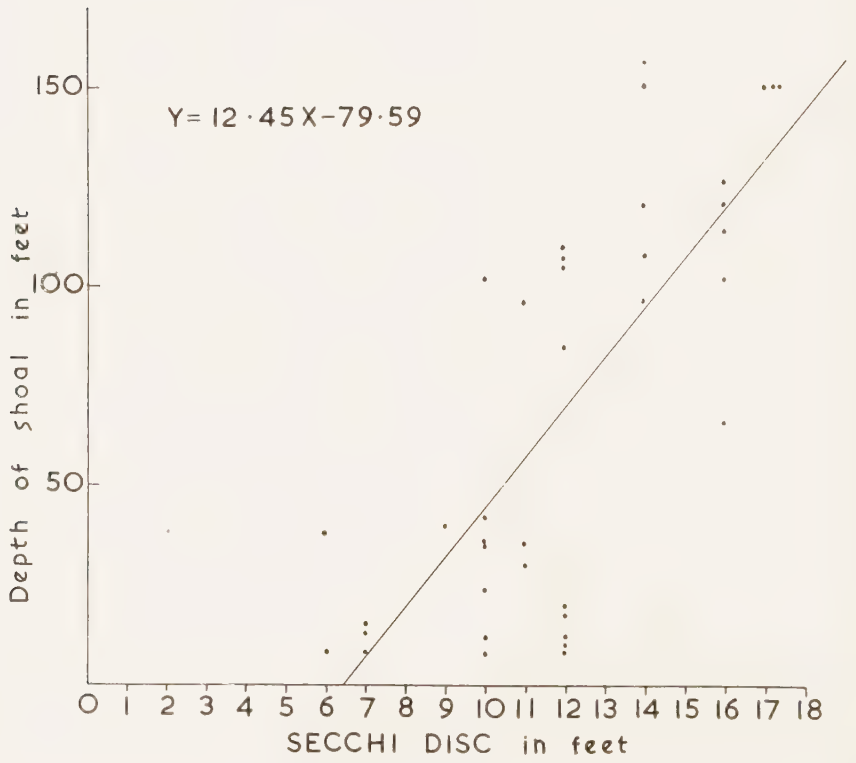


FIG. 7. The depth at which each shoal was found is plotted against Secchi disc readings taken at the same time as the shoal was recorded. In the top graph the shoals located in the early part of the season off East Anglia are plotted, and in the lower graph the shoals located later in the season are plotted. In each case a linear regression curve has been fitted.

From the evidence furnished by these tracings, it appears that the shoals lie, during the daylight, at varying depths, probably determined by the penetration of light, which in the turbid East Anglian waters is never great enough to force them to the bottom, and then during the hours of darkness, the shoals rise to a higher level. No evidence in favour of the rapid swim has been obtained from these tracings. The sudden filling of the nets, which is attributed by the fishermen to a rapid swim of the herring, is thought to be due to causes which will be dealt with in a future paper.

To test the influence of light penetration on the depth at which the shoals swim, Secchi disc readings were taken throughout the season and these, when plotted against the depth of the top of the shoal close to which they were obtained, show that there is a definite correlation between light penetration and the upward level of the shoal.

Fig. 7 shows two graphs constructed from these data. When a test of significance is applied there is a significant correlation between light penetration and the depth of the shoal. The Secchi disc is, of course, not a measure only of the intensity of the light, but, as it is the light penetration which affects shoal movement and this takes into account the turbidity of the water the state of the surface and the angle of the sun, the Secchi disc acts as a useful indicator of total light penetration. A relationship between light penetration and the level of the shoals in East Anglian waters is apparent from the data collected. While it has not proved possible to produce direct evidence from one continuous tracing as in the case of the sprat in the Thames estuary, there is every indication that there is no outstanding difference between the East Anglian shoals of herring and the shoals from other areas where vertical migration has been observed, although the very clear cut relationship between light and the depth of swim as seen on the Yorkshire coast, is not obtained.

(*d*) *In the Cap Gris Nez Area*

In December, large concentrations of herrings appear off the French coast close to Cap Gris Nez. These herrings are on the point of spawning and are therefore not feeding.

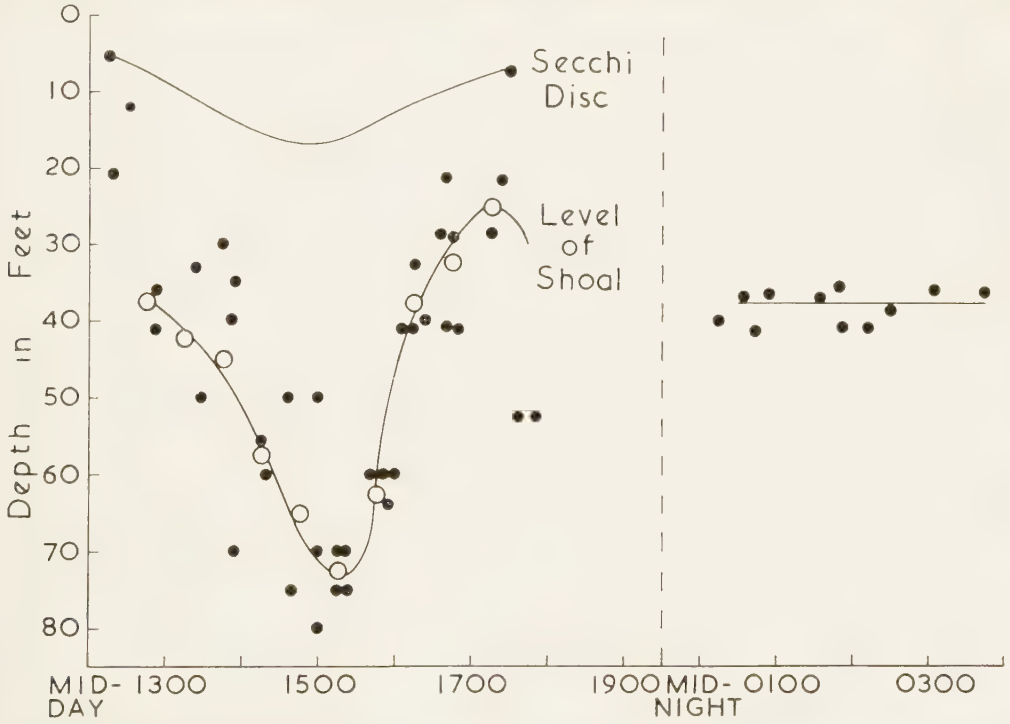


Fig. 8. Secchi disc readings are plotted against time and also the depth of the shoal. A comparison between light penetration and depth of the shoal is therefore possible. The level of the shoal during the night is shown.

On board the research vessel *Platessa* using a Marconi "Seagraph" sounder, a dense shoal of fish was located in this area during December, 1948, and continuous tracings were taken similar to those obtained on the sprat shoals in the Thames estuary. The depth at which

the upper limit of the shoal appears is plotted against time in Fig. 8 over a period extending from mid-afternoon until well after dark. It will be seen from Fig. 8 that the upper limit of the shoal falls on a curve, being nearer the surface at 1200 hours and 1700 hours and well down towards the bottom at 1500 hours.

As sunset was at 1600 hours, one would expect to see a curve in which the fish are down during the day, start to move up towards sunset, and stay well up during the night. The curve in Fig. 8 does show the upward movement towards sunset but in the portion of the graph before 1500 hours, the fish were much nearer the surface. However, the explanation is to be found in the Secchi disc readings taken at the same time, for when the shoals were near the surface the Secchi disc could only be seen at a depth of 5 feet. Later, at 1500 hours, the disc could be lowered to 17·5 feet before it disappeared from sight, and this coincided with a time at which the shoals were deeper in the water. Towards the eastern side of the area in which the shoal was found, and where the first tracings were obtained, the sea was extremely turbid and in plotting the vertical distribution of the herring shoal, this must be taken into account for it explains the apparent anomaly of fish being nearer the surface at mid-day than they were in the middle of the afternoon.

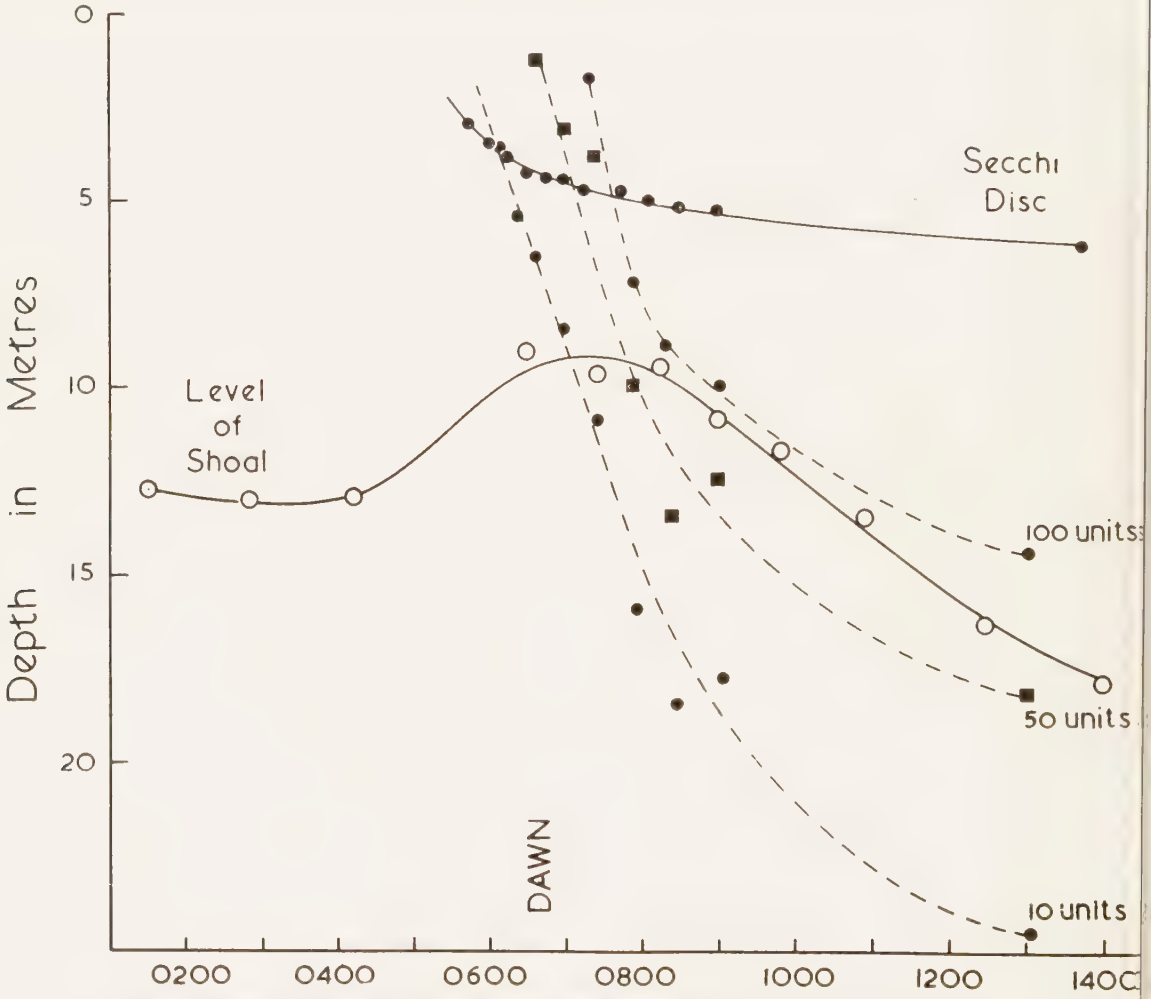


FIG. 9. The level of the top of herring shoals located near Sandettie Bank is plotted against time of day. Both Secchi disc readings and light intensity contours are indicated. The level of the shoal can be seen to rise towards the surface about dawn and then sink again to remain at a definite light intensity.

It is interesting to note that in the Cap Gris Nez area the shoals do display a vertical migration, although the movement is small, probably because the lower limit to which fish are forced by the light is not great, due to the poor light penetration in the turbid water of the area. Nevertheless, the fish are behaving in a like manner to the herring shoals found

in other regions. There is also a slight rise in the level of the shoals just after sunset, above the level at which the fish remain during the rest of the night. This is also found in the diurnal movement of plankton [Cushing (5)]. The rise of the shoal just after sunset is also seen just before sunrise.

This rise of the shoal a short time before dawn and which precedes the downward movement of the shoal associated with increasing light, is seen in tracings taken in November, 1950, close to the Sandettie Bank. On this occasion continuous records were obtained over many hours and in Fig. 9 the level of the top of the shoal has been plotted and also the Secchi disc readings taken at the same time. The rise from about 13 metres up to 9 metres shortly after dawn and the subsequent downward movement is clearly shown.

The light intensity was also measured by means of a photocell at intervals from dawn until 1300 hours. The 10, 50 and 100 unit light intensity contours are shown in Fig. 9. There is up to a 50% error on these readings, but the shoal still falls within a definite light intensity. From dawn until about 0830 hours there is a rapid increase in the amount of light as measured by the photocell, but there is very little downward movement of the shoal. After about 0830 hours the shoal begins to descend more rapidly and in so doing the light intensity at the depth of the top of the shoal is kept at roughly the same intensity, and towards mid-day as the photocell readings fail to increase for a given depth, the shoal remains at a steady level. The rise to an optimum light intensity at dawn, followed by a more rapid downward movement, is related by Jones (verbal communication) to active swimming of fish above a certain light intensity, and also by Cushing in connection with the vertical migration of planktonic crustacea.

The shoal can be seen to rise at dawn towards the surface. A similar rise above the night level is seen in Fig. 8, but in that case, it took place at dusk.

(*e*) *Comparison of Areas*

The shoals off North Shields tend to come up closer to the surface than the shoals off Yorkshire and Cap Gris Nez during darkness, and in the "between" lights at sunset and dawn. The Yorkshire fish never rose above 10 fathoms except at the end of the 1949 season whilst the Cap Gris Nez fish remain at a level of between 6 and 7 fathoms during the night. It may be that there is a relationship between the upper limit reached by the shoal and the total depth of water in the area. For instance, off the Yorkshire coast the average depth of the sea bed is 30 fathoms and the shoals rise to 10 fathoms, off Cap Gris Nez the bottom is at about 18-20 fathoms and the fish rise to 6 or 7 fathoms. In each case, a ratio of 1 : 3 is found.

In all areas examined there was a relationship between light intensity and the depth at which herring and sprat shoals are found. It might be thought that the fish are normally to be found in the upper waters because that is where the food is in abundance, and that it is the increasing light intensity which forces the fish down to a lower level. In other words, the fish are to be found normally at the level of most abundant food supply, and any change from this level is due to the light intensity.

Certainly this theory would seem to fit the facts for the herrings off the Northumberland coast for, when these herrings are examined, they are found to be full of food, most of which is *Calanus spp. Calanus* is restricted in its distribution to a layer that varies in depth according to the light intensity. In the same area off the Northumberland coast the herring shoals were found to lie at an average depth of 23·9 fathoms during the day and 15·7 fathoms during the hours of darkness.

In the other areas off Yorkshire, however, and off East Anglia and also in the Thames, where the sprats show a similar diurnal movement, the fish are not feeding, being in an advanced stage of maturity. In none of the herring or sprat stomachs examined at the time of obtaining the evidence of diurnal migration given in this paper, except those of the North Shields area, was any food found. This means that the urge for the fish to regain its former level is not caused directly by the urge to feed but is controlled by some other influence. One would expect that if the feeding urge was the causal effect of a return to

the upper waters when the light intensity permits and this urge to feed was removed, the fish would remain at the same level all day irrespective of light intensity, and that the level would be the one to which the shoals were forced at maximum light intensity.

Some other cause for the upward movement must be sought for the non-feeding fish. The possibility for the rise being due to a habit acquired when feeding which remains throughout the non-feeding period, should not be overlooked.

Alternatively, the rise of the fish might be explained by a similar hypothesis to that referred to by Cushing (5) for the migrations of planktonic crustacea. But the fact that the fish take up a definite level during the hours of darkness and do not scatter must be explained and it is suggested that the night level of the fish is probably that at which they are in hydrostatic equilibrium.

Thus the reason that the fish of Yorkshire and of Cap Gris Nez remain at a definite level during the night, could be due to their being in hydrostatic equilibrium at that depth. To some extent the East Anglian fish show a similar rise to a definite level but it is masked because of the mixture of maturity stages.

The fish have been shown to rise to one-third of the total depth of the water in two of the areas discussed. This ratio may have some significance for, the deeper the water the less turbid it is, and therefore the greater the light penetration. If the light penetrates to greater depths in the less turbid deeper water the fish will be forced further down during the day and consequently become, during the period of time which they remain in the area, adapted to greater pressures of water by reason of the swim bladder. If the swim bladder, as a regulatory organ, is restricted in its adaptability to varying pressures [Jones (7) suggests that the adaptability is slow] a pattern would be imposed on the vertical movement, and in this way the range would be restricted.

Taylor (8) gives the theoretical sizes of swim bladders needed by fish of known specific gravity, in order to be in equilibrium at certain pressures and salinities. Future work will be designed to obtain the fat content and air bladder size of the herrings for the various areas described in order to find the depth at which the fish are in equilibrium.

FIG. 10. The shoal below the ship can be seen at 10 fathoms from the surface. When the searchlight is operated at the points indicated a well defined change in level of the top of the shoal can be seen.

II. REACTION OF FISH SHOALS TO ELECTRIC LIGHT

The effect of daylight illumination on the shoals has been described, and it has been seen that the pelagic fish alter their depth in response to variations in light intensity.

As additional confirmation, a searchlight was directed vertically over the side of the ship on to shoals of herring and pilchards and the reaction of the shoal noted on the echo-sounder.

1. **Herrings**

(a) In the Yorkshire Coast Area

The Yorkshire herring shoals, of which Fig. 10 is a typical tracing, remain throughout the night at a level of 10 fathoms. As soon as the light is switched on the shoals sink, returning to their former level when the lamp is switched off. The tracing in Fig. 10 was made on the fathom scale, but a clearer picture of the reaction of the shoals to the lamp can be seen in Fig. 11. In this figure the foot scale is used, with a range of 0 to 120 feet from the surface to the bottom of the paper. The sea bed at 30 fathoms is therefore off the tracing, but an enlarged picture of the top of the shoal is obtained. The fathom

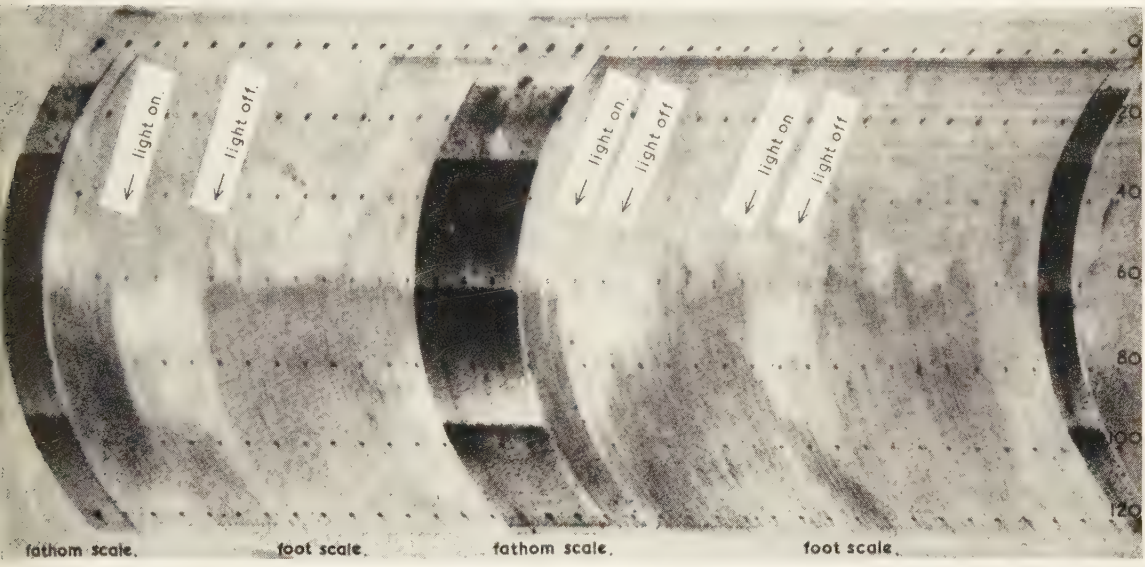


FIG. 11. The tracing similar to that shown in Fig. 10, but recorded on the foot scale, shows the reaction of the fish to a searchlight more clearly.

scale is also used. The point at which the light is switched on and off is marked on the tracing and it will be noted that the top of the shoal immediately sinks from 63 feet to 100 feet and, when the light is switched off, returns to its former level at 60 feet. The rapidity of the reaction of the shoal is most marked in each case and suggests that if the fish actually move down they do so at a rate of about 3 miles an hour, which, over short distances, sounds a reasonable speed.

(b) In the East Anglian Area

Fig. 12 is a tracing of herring shoals in East Anglian waters during November, and shows that the East Anglian herring react in a similar manner. In this case the top of the shoal descends from 24 feet to 44 feet within a matter of seconds and then descends a little further to 50 feet before the light is switched off. The shoal is a little slower in regaining its former level, but within a minute of the light being switched off it is at 30 feet, after which it rises slowly to about 24 feet.

(c) Cap Gris Nez Area

The reactions of the fish in each area might be expected to differ somewhat because the light used differed. A 24 volt 60 watt Aldis lamp was used from the *Clupea* off the Yorkshire coast, and from *Sir Lancelot* off Cap Gris Nez, whereas from the *Onaway* a 24 volt 60 watt, searchlight was used on the East Anglian shoals. Also the water off Yorkshire was clearer than that off East Anglia.

The Cap Gris Nez herrings showed a slower reaction to the light. Only a gradual descent was noticed from 10 fathoms to 16 fathoms and a return to 12 and then 10 fathoms.

This movement of the herring away from the light beam need not necessarily be a downward movement. It could be argued that there was a scattering of the fish laterally out of the beam of the light, but in either case it is apparent that the fish are avoiding the light. On closer examination of the tracings, however, it will be seen that not only does the top of the shoal descend in level but also the bottom of the shoal. In Fig. 12 this is particularly obvious and suggests that the shoal moves bodily downwards until it reaches a level at which the light intensity is not too great. The majority of these herrings were young immature fish or fish in the early stages of maturity.

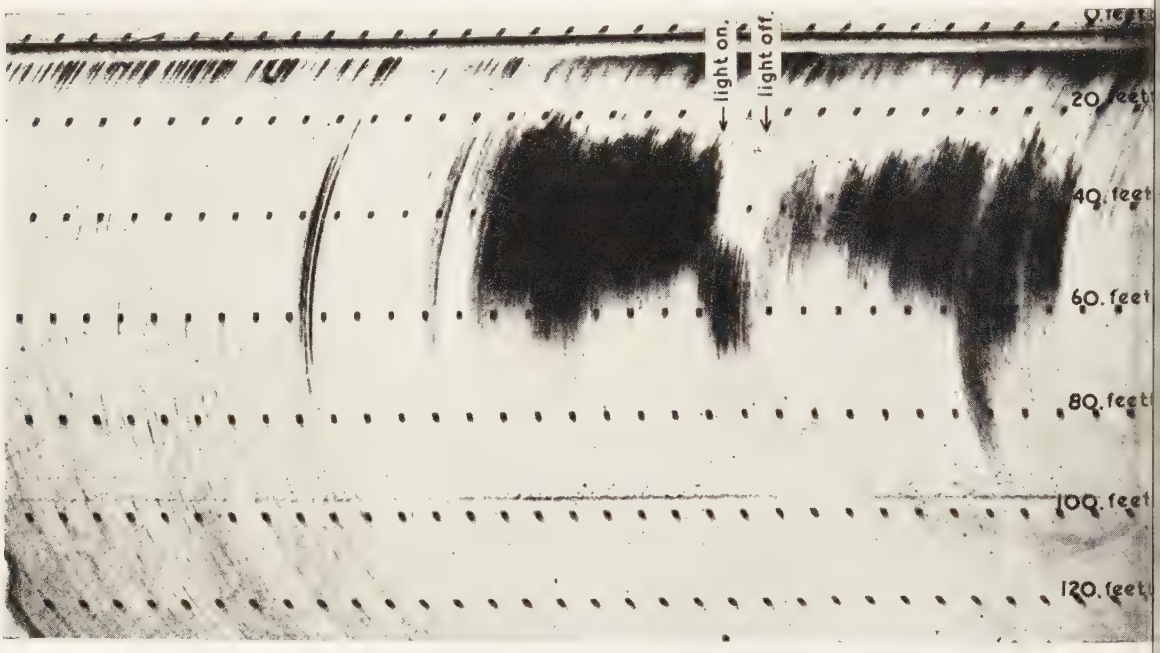


FIG. 12. The effect of a searchlight shone vertically on to a shoal of herrings in East Anglian waters is shown in the above tracing. Notice that the shoal appears to move bodily down when the light is switched on.

According to the Norwegian fishermen herrings in more northern waters react to a bright light such as a searchlight by coming up towards the source of light. It was because of Norwegian experience that the experiments described here were carried out, but with entirely different results.

2. **Pilchards**

When the 24 volt searchlight used on the herrings in East Anglia was directed on to a shoal of pilchards the tracing reproduced in Fig. 13 was obtained. The shoal, when first located, was at a depth of 50 feet. The light was switched on and the shoal went down, but after 1½ minutes it began to rise until it became well up towards the surface, and although the main bulk of the fish rose to about 23 feet, some fish were actually seen playing on the surface of the water. The shoal remained well up until the light was switched off and then once more returned to its former level. On other occasions it was found that the pilchards could be kept up at the surface whilst the ring-net was shot round the shoal by keeping the light directed on a spot in the middle of the ring. In this case the pilchard shoal reacted to the light by going down immediately it was turned on but there followed, after this initial move, a rise in the level of the shoal. During the hours of daylight pilchard shoals are to be found deeper in the sea than at night.

The searchlight has been kept on for periods of up to 5 minutes over herring shoals off Yorkshire, during the whole of which time the fish remained at the lower level. This was done in order to be quite certain that it was not merely the initial descent prior to the upward movement (as seen in the case of pilchard shoals) which was being observed.

3. Fish Fry

On many occasions when the searchlight has been used, small fish have collected in the beam of light. Off Cap Gris Nez very large numbers of sand eels collected all round the beam just a few inches below the surface of the sea. In mid-summer in Cornwall large numbers of small fish congregated round the light although only stray fish were seen before the light was switched on.

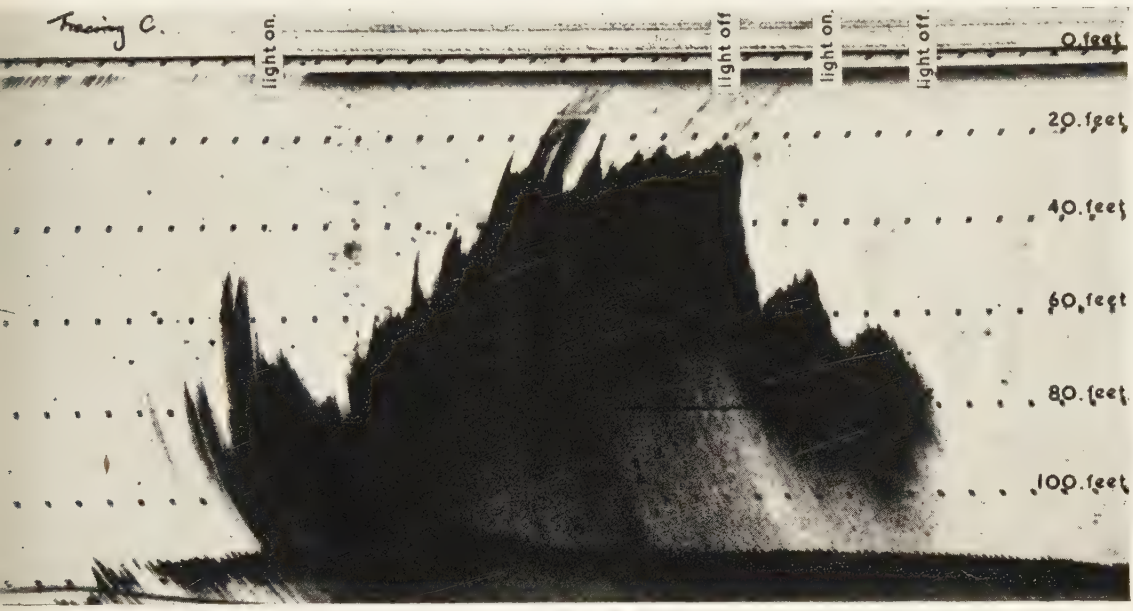


FIG. 13. A tracing of a shoal of pilchards showing the reaction of the shoal to electric light.

On one occasion in Mount's Bay after steaming for some time looking for fish on the echo-sounder without result, the ship was stopped and the searchlight directed vertically over the side. The resultant tracing on the echo-sounder is reproduced in Fig. 14. Slowly, on a clear paper, a dark tracing which became well defined after a few minutes, appeared. This tracing was obtained whilst the light remained on, but as soon as it was switched off (indicated in the figure), the tracing began to thin out as though the organisms from which the echo was produced, began to scatter. This scattering continued until the tracing nearly disappeared and then the light was again switched on. When this was done, the echo came back again as clear as it was before the light was switched off. This tracing was due to small fish which could be seen swimming about near the surface in large numbers. It is thought that the fish might have been pollack fry of about 2 to 3 inches in length. Certainly the tracing was quite unlike any recorded from pilchard, herring or sprat shoals. It is rather interesting to note that there is a tendency for the shoal to be slightly higher during the periods of darkness when there was no illumination from the searchlight.

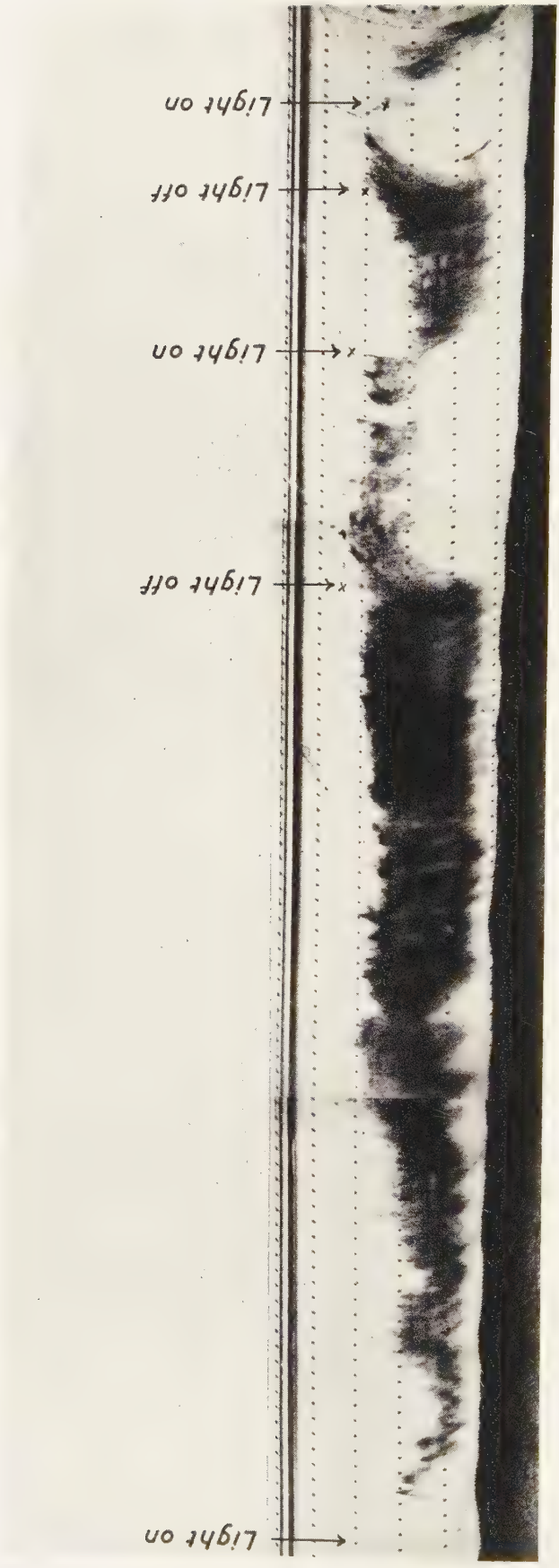


FIG. 14. A tracing obtained off Cornwall in which a shoal of fish is collected by the searchlight. (See text for explanation.)

SUMMARY

Shoals of sprats and herrings show a diurnal migration, coming up towards the surface at night and moving down during the day.

The extent of this vertical migration varies in different areas of the southern North Sea.

The diurnal migration takes place in both feeding and non-feeding fish.

The downward movement of the shoals is shown to be associated with increase in light intensity, which is thought to be the operative cause. It has been shown that the fish remain within a certain light intensity during the day. The fish would therefore have to swim downwards to remain in that light intensity. The level at which the shoals remain during the night appears to be definite, and specific gravity seems to be the most likely cause to investigate.

An upward movement of the herring shoal, above that of the night level, immediately precedes the downward movement associated with increasing light at dawn. A similar upward movement is seen at dusk before the shoals settle to their night level.

The behaviour of the East Anglian herring shoals is analysed and found to be essentially similar to that of herring shoals in other areas of the North Sea.

Herring shoals have been shown to avoid electric light of certain intensities.

Examples are given of the way in which pilchards and certain fish fry are attracted to electric light.

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